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[21] Appl. No. **867,044**
[22] Filed **Oct. 16, 1969**
[45] Patented **Oct. 5, 1971**
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[32] Priority **Oct. 23, 1968**
[33] **France**
[31] **170,945**

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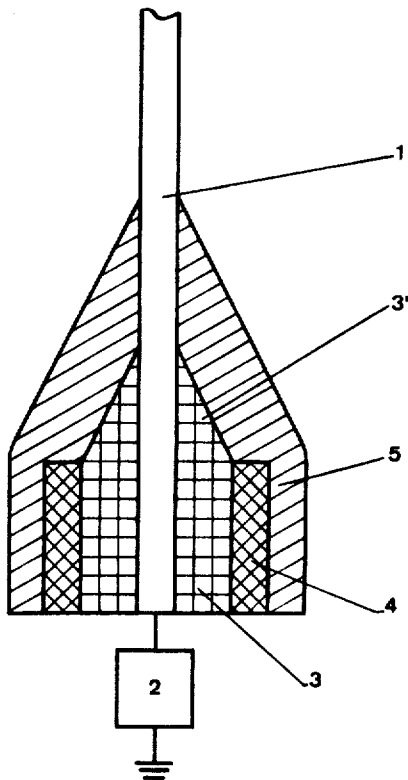
[54] **WIDE BAND ROD ANTENNA WITH IMPEDANCE**
MATCHING
7 Claims, 7 Drawing Figs.
[52] U.S. Cl..... **343/750,**
343/787, 343/861, 343/900
[51] Int. Cl..... **H01q 9/00**
[50] Field of Search..... **343/745,**
750, 787, 788, 900

[56] **References Cited**
OTHER REFERENCES

Electronics, page 159, 160, and 161, Jan. 1, 1957 copy
343-787

ABSTRACT: A fraction of the antenna wire is coupled with a
ferromagnetic material the electrical parameters of which
meet the following condition:
$$L_1 C_1 = 1/16 L^2 \cdot 1/f^2$$

where L_1 is the unitary inductance per unit of length of the
wire surrounded by the ferromagnetic material.
 C_1 is the corresponding unitary capacitance.
 L is the geometrical length of the antenna.
 f is the operating frequency which varies within the operat-
ing bandwidth.
The ferromagnetic material is to be chosen so as to meet
equation 1. As will be explained in further details, some fer-
romagnetic materials suitable for this use are commercially
available. Available magnetic materials which do not comply
with law (1) may be forced to comply through automatic con-
trol.



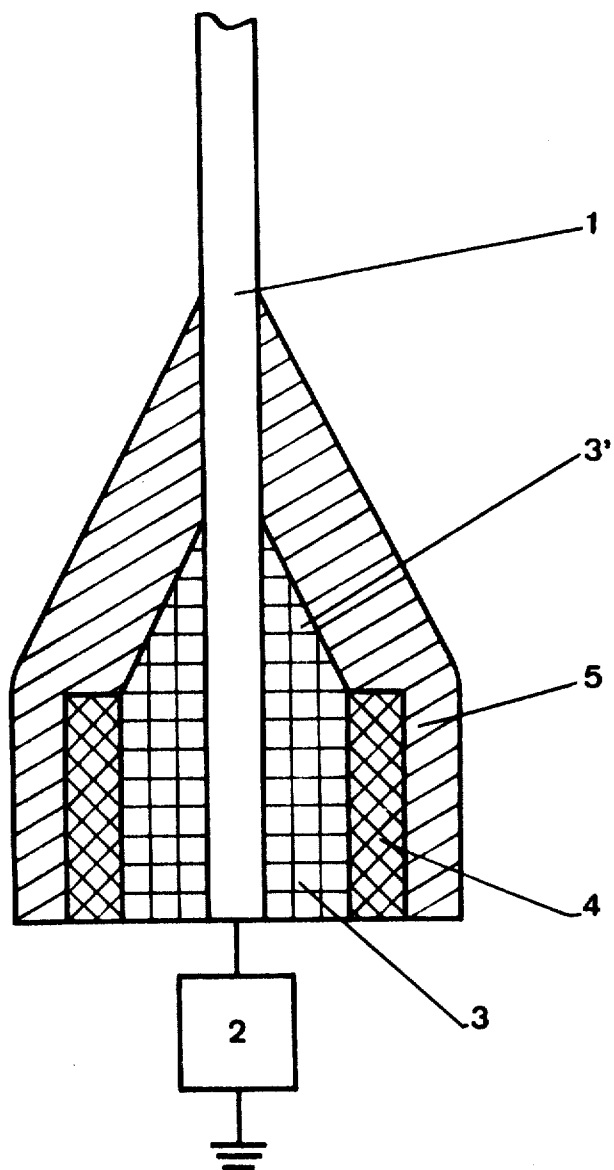


FIGURE 1

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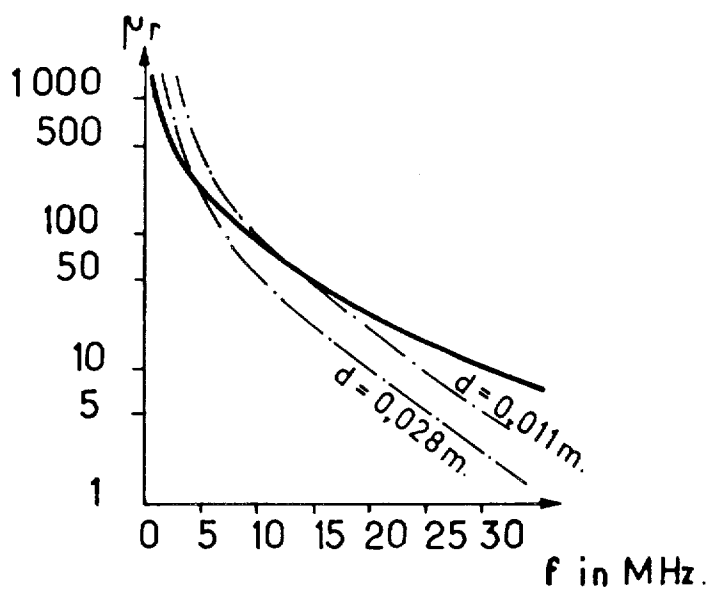


Fig. 2

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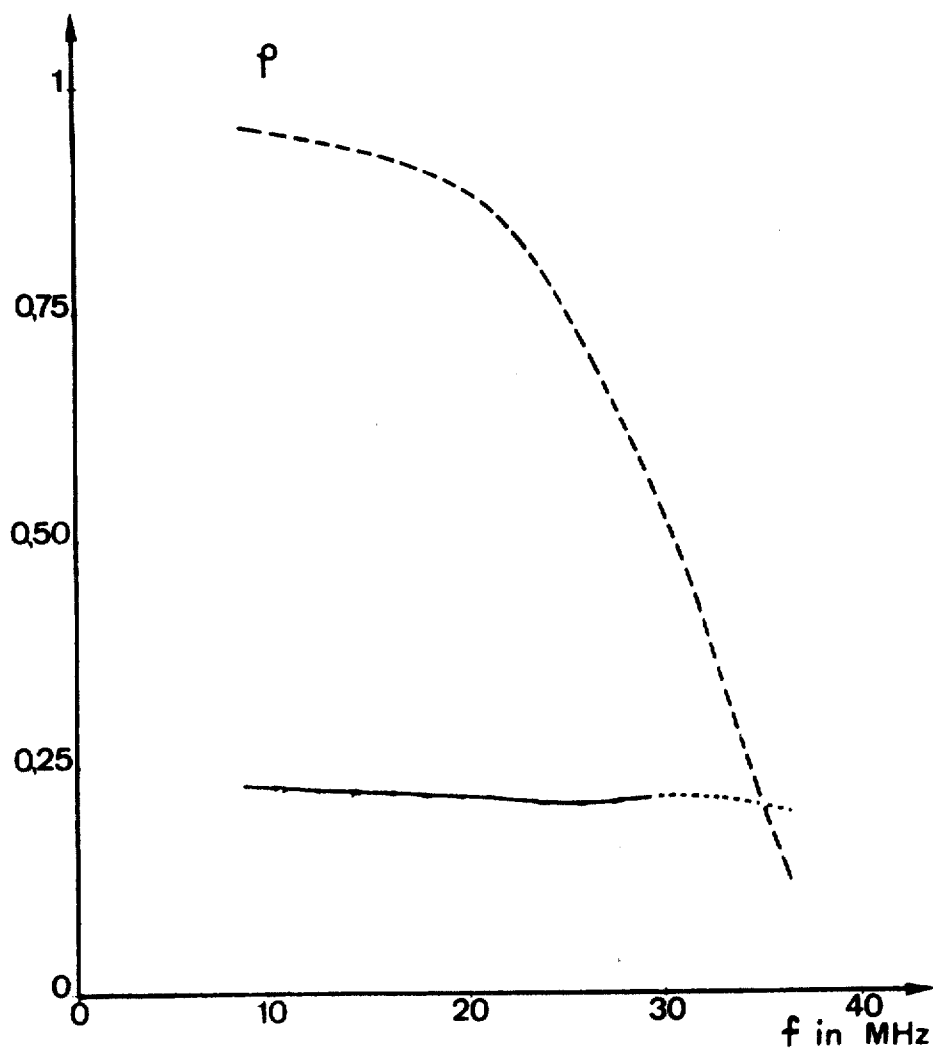


FIGURE 3

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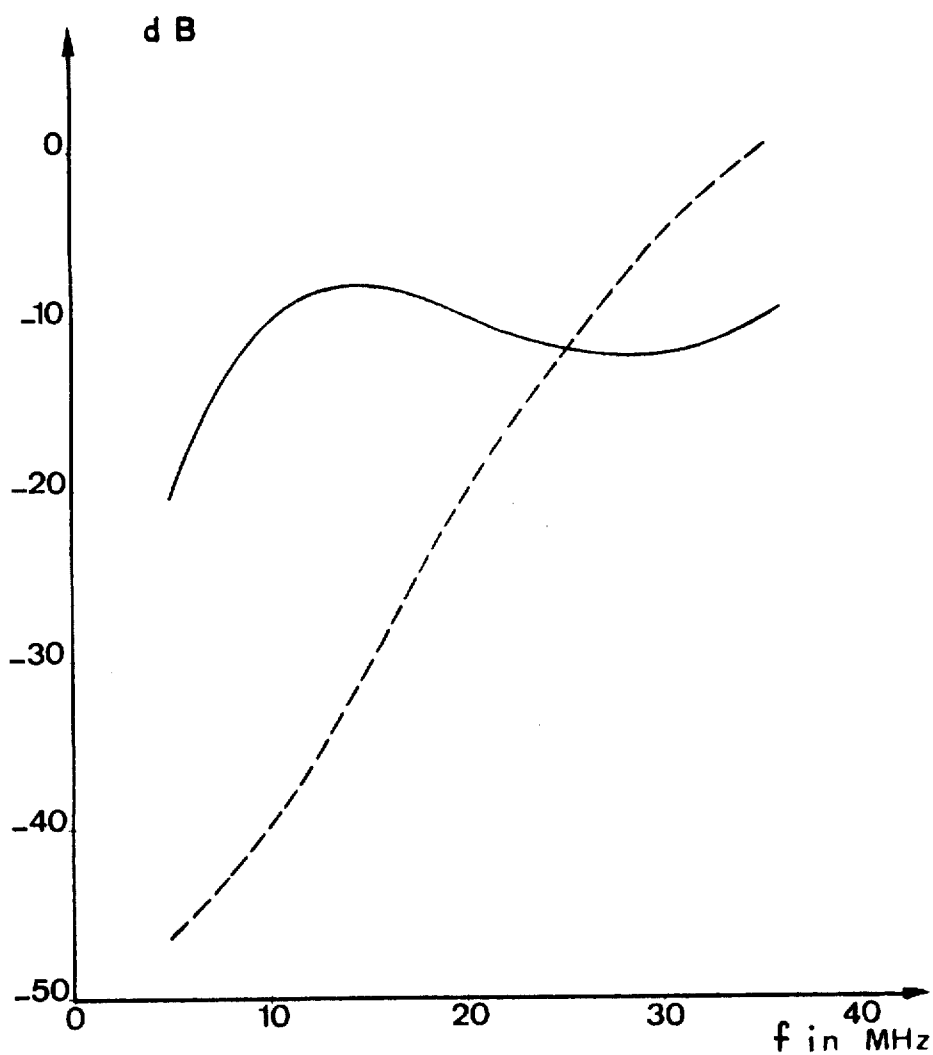


FIGURE 4

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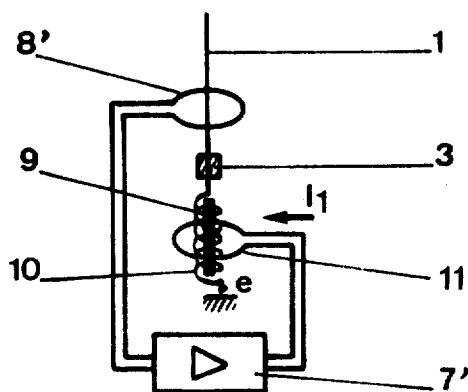


FIGURE 6

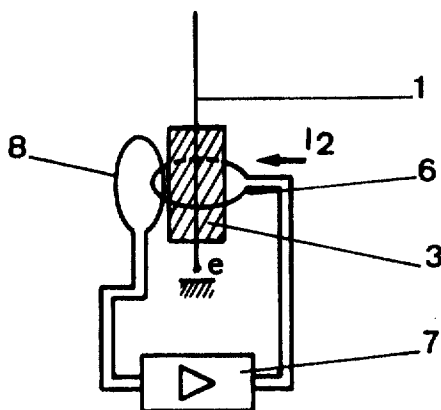


FIGURE 5

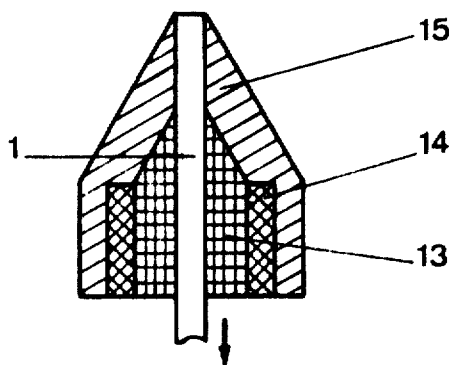


FIGURE 7

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WIDE BAND ROD ANTENNA WITH IMPEDANCE MATCHING

BACKGROUND OF THE INVENTION

The present invention relates to an improvement in wide band antenna design and more particularly to mobile equipment antennas. Wide band means a bandwidth which covers several octaves. In mobile equipment, it is current practice to use an antenna consisting of a plain wire mechanically and electrically connected at one of its ends. The length of the wire has to be related to the wavelength in order to obtain maximum gain. When the length of the antenna differs from the optimum value, the gain decreases rapidly. Wire antennas are therefore small bandwidth designs. It has been proposed to widen the operating bandwidth through the addition of a matching unit. Such matching units are difficult to design to cover a bandwidth as large as mentioned above. They always introduce a loss in the circuit which reduces maximum gain.

BRIEF DISCLOSURE OF THE INVENTION

The present invention concerns an antenna design which does not spoil the mechanical simplicity and robustness of the wire antenna and allows a several octave coverage. According to the main feature of the invention, a fraction of the antenna wire is coupled with a ferromagnetic material, the electrical parameters of which meet the following condition:

$$L_1 C_1 = 1/16 L^2 1/f^2 \quad (1)$$

where L_1 is the unitary inductance per unit of length of the wire surrounded by the ferromagnetic material.

C_1 is the corresponding unitary capacitance.

L is the geometrical length of the antenna.

f is the operating frequency which varies within the operating bandwidth.

The ferromagnetic material is to be chosen so as to meet equation 1. As will be explained in further details, some ferromagnetic materials suitable for this use are commercially available. Available magnetic materials which do not comply with law (1) may be forced to comply through automatic control.

According to the teaching of the invention, the ferrite need not be located on the whole length of the antenna wire. It may be localized around a section less than one-tenth of said length so that it will practically not spoil the mechanical characteristics (flexibility—weight, etc. ...) of the design.

According to another feature of the invention, condition (1) is met through biasing of the ferromagnetic material by means of an auxiliary DC magnetic field either constant or automatically varied. The use of such an external magnetic field increases the choice of ferromagnetic materials suitable for the purposes of the present invention. Indeed, condition (1) can be met by three classes of magnetic materials:

a. magnetic materials with constant permeability in the frequency band (permeability meets condition (1)).

b. ferromagnetic materials with constant permeability in the operating frequency band (permeability varies according to condition (1)).

c. ferromagnetic materials in which both permeability and permeability vary so as to meet condition (1).

In the case of materials of the class a), it is preferred to locate the material at the base of the antenna (maximum current point) for largest influence of the material. The biasing field, when required, is easily applied through a coil at the base of the antenna. The class of materials b) above should be located at the point of the antenna where voltage is maximum, that is at the top of the antenna for maximum efficiency.

PRIOR ART

The use of ferromagnetic materials in association with an antenna wire has already been described in the prior art. U.S. Pat. No. 3,302,208 filed Mar. 20, 1964 by Harold S. Hendrickson discloses a dipole antenna including ferrite sleeves surrounding the dipole arms at the feeding point. The aim of this ferrite loading is to reduce the geometrical length of the

antenna. No specific requirement for the electrical parameters of the ferrite is mentioned in this patent. It is even mentioned that for each particular design, the electrical characteristics of the ferrite should be chosen according to the operating frequency and the maximum length of the antenna which can be tolerated. According to the teaching of the present invention, the widening of the operating frequency band lies on the fact that equation 1 is met.

DETAILED DESCRIPTION OF THE INVENTION

The invention will be better understood by reference to the following description and the accompanying drawings in which:

FIG. 1 is a first embodiment of the invention.

FIG. 2 is a plotted curve showing the variation of permeability of the ferromagnetic material used in the antenna of FIG. 1.

FIGS. 3 and 4 show the reflection coefficient of the antenna versus the frequency and the transmission losses between two identical antennas in the same frequency band.

FIGS. 5 and 6 show two automatic control devices for the DC biasing magnetic field.

FIG. 7 is another embodiment of the invention.

FIG. 1 shows the base of a wire antenna 1 connected to an equipment 2 (either a receiver or a transmitter). The base of wire 1 is surrounded with a ring of ferromagnetic material 3 the upper extremity of which is tapered as shown at 3' so as to provide for a progressive matching of impedance between the base of the antenna and its free end. The cylindrical lower part of ring 3 is surrounded with a ring 4 made of a dielectric material provided to match the impedance of the loaded part of the antenna with that of the surrounding space. The base of the antenna is entirely packaged in an insulating resin 5 such as a very low density polyurethane resin which reproduces the cylindro-conical shape of ring 3. Potting 5 is necessary to secure the antenna mechanically and to protect the rings 3 and 4. It should preferably consist of a low permittivity insulating material in order not to disturb the impedance matching provided by ring 4. According to the invention, magnetic material of ring 3 meets equation 1 in the operating frequency. The ferrite material sold by the assignee of this application under the trade number 1401 meets the requirement in the 0 to 30 MHz band as shown in FIG. 2 and table 1.

Ring 4 is made of a dielectric material, the permittivity of which is chosen in order to match the permittivity of the ferrite material of ring 3 to that of the air. In the embodiment just described, the permittivity of ring 4 is preferably about 4. The material which is commercially sold by the assignee of this application as trade number D 6226 meets the requirement. It is a mixture of polythene and titanium dioxide. Of course, any other available dielectric material with a permittivity of 4 can be used for ring 4.

FIG. 2 shows the measured variation of the permeability of LTT-type 1401 ferrite versus frequency. The permittivity of this material is constant in the frequency band considered (10–30 MHz) as is shown on table 1 which gives the value of the capacity of the complete antenna structure at different frequencies within the operating band.

Table 1

Frequency in MHz	10	20	30
C in pF	11.0	12.1	11.4

Condition (1) can easily be related with the variation of permeability of the ferrite versus the frequency. As C_1 is constant, it is only necessary to consider L_1 . As is well known (cf. for instance "Inductance calculation" by F. W. GROVER published by D. VAN NOSTRAND in 1946, page 35) the unitary inductance of a nonmagnetic wire of length L and radius r is given by:

$$L_1 = .2 \left[\log \frac{2L}{r} - \frac{3}{4} \right]$$

in μH L and r in centimeter

The increase of said inductance due to the magnetic material surrounding the wire is:

$$\Delta L_1' = \mu \frac{\text{Log } \frac{d}{r}}{2\pi} \quad (2)$$

where μ = permeability of the material,
 r = the internal radius of the sleeve and
 d = the external radius of the same.

(2) can easily be calculated from Ampere's law. Considering the magnetic field H established at point within the magnetic sleeving at r_0 from the axis of the wire by the current I through said wire, the law is:

$$H = (1/2\pi)(I/r_0) \quad (3)$$

The electromagnetic energy stored within the elementary volume of magnetic material at r_0 from the axis and of unitary length is:

$$\Delta W = \frac{1}{2} \mu H^2 2\pi r_0 dr_0$$

The energy within the unit of length of sleeve is:

$$W = \int_r^d \Delta N = \frac{1}{4\pi} \mu I^2 \text{Log } \frac{d}{r}$$

when H is replaced by its value according to (3).

The increase in inductance $\Delta L_1'$ per unit of length is:

$$\Delta L_1' = \frac{2W}{I^2} \text{ Henry} = \frac{\mu}{2\pi} \text{Log } \frac{d}{r}$$

Considering the relative permeability:

$$\mu_r = \frac{\mu}{\mu_0} = \mu 2\pi 10^{-7}$$

$$\Delta L_1' = .2\mu_r \text{Log } \frac{d}{r} \text{ in } \mu H$$

Therefore the unit length inductance of the wire covered with the magnetic material:

$$L_1 = L_1' + \Delta L_1' = .2 \left[\text{Log } \frac{2L}{r} - \frac{3}{4} + \mu_r \text{Log } \frac{d}{r} \right]$$

Condition (1) becomes (with $C_1 = 12 \text{ pF}$):

$$2.10^{-7} \left[\text{Log } \frac{2L}{r} - \frac{3}{4} + \mu_r \text{Log } \frac{d}{r} \right] = \frac{10^{12}}{12 \times 16} \cdot \frac{1}{L^2} \cdot \frac{1}{f^2}$$

Or

$$\mu_r = \frac{1}{\text{Log } \frac{d}{r}} \left[\frac{2.64 \times 10^{16}}{L^2} \cdot \frac{1}{f^2} - 5, 9 \right] \quad (4)$$

FIG. 2 shows as a plain line the measured values of μ_r with respect to frequency. The two interrupted line curves are the theoretical curves calculated from (4) for $r=0.4 \text{ cm.}$ and the values of d mentioned in the figure.

As can be seen, the measured values fit quite well with the calculated values from equation (4).

FIGS. 3 and 4 show the operating characteristics of an antenna design according to the invention (full-line curves) with respect to a prior art wire antenna of the same geometrical length (interrupted line curves). FIG. 3 shows the reflection coefficient of the antenna between 10 and 35 MHz.

FIG. 4 shows the transmission losses between two identical wire antennas connected respectively to a transmitter and to a receiver. The transmission loss is the ratio between the transmitted energy and the received energy. Obviously, the value of the losses depends of the length of the transmission path. The variation of the losses with respect to frequency, however, is independent of the path length. As can be seen, the loss of the prior art wire antenna varies much in the 10 to 30 MHz band (from -40 db. up to almost 0) in the same frequency band. The loss in the transmission established with antennas according to the invention remains practically constant and equal to

-12 db. FIGS. 3 and 4 correspond to an embodiment of the invention according to FIG. 1 with the following geometrical dimensions:

- length of the aerial 1 : 210 cm.
- height of the ferrite ring : 20 cm.
- diameter of the wire r : 0.4 cm.
- external diameter of the ferrite ring d : 0.7 cm.

It may occur that the designer will not find a ferrite meeting condition 1 in the operating frequency band. According to the invention, the variation of the ferromagnetic material parameters in the operating band are modified by a biasing magnetic field. FIG. 5 shows schematically such a design. The antenna wire shown at 1 is surrounded at its lower extremity by the magnetic ring 3. An external magnetic DC field is established in ring 3 by means of coil 6. Coil 6 is fed through an electronic device controlled by the signal picked-up by loop 8 located in the field radiated by the antenna. Electronic device 7 is designed in order to maintain the impedance of the antenna constant that is to say to maintain the radiated field picked-up by loop 8 constant. The variation of the feed current to coil 6 is thereby automatically matched to the permeability variation of the magnetic material so as to meet relation 1.

Device 7 is essentially constituted by a linear wide band amplifier. In the case of the above example where the antenna should cover the band from 10 to 30 MHz, the bandwidth of the amplifier is 2-30 MHz. The amplifier is fed with the pickup loop 8 signal and feeds an automatic gain control circuit which feeds the magnetizing coil 6 through a DC rectifier. Experience has shown that, provided the wire antenna is designed for maximum gain at the upper limit of the frequency band, a linear automatic control is sufficient for practical purposes. It should be mentioned that the theoretical study of the circuit is rather complex since two independent phenomena are to be considered: the first one is the variation of the permeability versus frequency and the second the variation of permeability with applied field (the current in coil 6 varies). The second phenomenon is out of reach of the designer. The first may be adjusted through a correct selection of parameters r and d , as shown in FIG. 2.

FIG. 6 is another embodiment of the electronic control device associated with the magnetic material. The antenna is constituted of wire 1 the base of which is surrounded with the ferrite ring 3 as previously described. Wire 1 is serially connected with an additional inductor made of a coil 9 surrounding a ferromagnetic rod 10. This inductor is mechanically independent of radiating wire 1. The control device varies inductance of the 9-10 unit through an auxiliary DC magnetic field applied to the ferromagnetic rod 10 by means of coil 11. The current fed into 11 is delivered by an electronic regulator 7' controlled by the signal picked-up by loop 8' which is representative of the value of the current flowing in conductor 1. Electronic regulator 7' is set so as to control the current through coil 11 so as to modify the value of inductance 9-10 to maintain constant the current flowing through 1.

Instead of direct control of regulators 7 and 7' by pickup loops 8-8' in FIGS. 5 and 6, it is also possible to use a program generator designed so as to meet the requirement.

FIG. 7 shows another embodiment of the invention using a ferromagnetic material with a constant permeability in the operating frequency band. The mathematical relation between the permittivity and the frequency for condition (1) can be established as has been described above with reference to the permeability. The calculations are more complex and will therefore be omitted here. Once the theoretical law obtained the selection of the material is made by comparison with the measured curves for the same frequency band. Should no material appear to meet the requirement in the band, the permittivity of the material may be controlled so as to meet condition (1) through the use of an adjustable capacitance connected serially or in parallel with the loaded part of the antenna. For instance, a varactor-type diode is used to match the variation law of the permittivity versus the frequency with condition (1). In FIG. 7, the free end of the

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wire is surrounded with ring 13 made of the magnetic material. Ring 13 is surrounded with ring 14 made of a dielectric material intended to match the impedance of ring 13 with the impedance of the air. This has already been explained. Potting 15 is provided to mechanically protect the assembly 13-14.

One example of a ferromagnetic material which would be useful in connection with the structure for FIG. 7 and which is manufactured by the assignee of this application is known as "Fermalite 1008." This is a manganese ferrite material, the permeability of which is about 150 and is substantially constant in the 1 to 10 MHz band.

What we claim:

1. A wide band wire antenna consisting of a conductive non-magnetic wire partially surrounded with a magnetic sleeve selected so that in the operating bandwidth

$$L_1 C_1 = 1/16 \pi^2 1/f^2$$

where L_1 is the inductance of the sleeved wire per unit of length;

C_1 is the capacitance of the same;

L is the wire length;

f is the operating frequency within the band.

2. A wide band wire antenna consisting of a conductive non-magnetic wire partially surrounded with a magnetic material sleeve serially connected with an adjustable lump impedance so that:

$$L_1 C_1 = 1/16 \pi^2 1/f^2$$

where L_1 is the equivalent inductance of the unit of length of the sleeved wire and the lump impedance;

C_1 is the equivalent capacitance of the same;

L is the wire length;

f is the operating frequency within the band.

3. A wide band wire antenna according to claim 2 in which the lump impedance is controlled by an automatic control device fed by the field radiated by the antenna.

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4. A wide band wire antenna according to claim 2 in which the lump impedance is controlled by means of a program.

5. A wide band wire antenna consisting of a conductive non-magnetic wire surrounded over not greater than 10 percent of its length with a magnetic sleeve selected so that in the operating bandwidth

$$L_1 C_1 = 1/16 \pi^2 1/f^2$$

where L_1 is the inductance of the sleeved wire per unit of length;

C_1 is the capacitance of the same;

L is the wire length;

f is the operating frequency within the band.

6. A wide band wire antenna consisting of a conductive non-magnetic wire the remote from feed end of which is surrounded with a sleeve of magnetic material having a constant permeability in the frequency band and a permittivity which varies according to

$$L_1 C_1 = 1/16 \pi^2 1/f^2$$

where L_1 is the inductance of the sleeved wire per unit of length;

C_1 is the capacitance of the same;

L is the wire length;

f is the operating frequency within the band.

7. A wide band wire antenna consisting of a conductive non-magnetic wire the feed end of which is surrounded with a sleeve of magnetic material having a constant permittivity in the frequency band and a permeability which varies so that:

$$L_1 C_1 = 1/16 \pi^2 1/f^2$$

where L_1 is the inductance of the sleeved wire per unit of length;

C_1 is the capacitance of the same;

L is the wire length;

f is the operating frequency within the band.

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